The Crab Nebula and Pulsar in the MeV Energy Range

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ABSTRACT

The imaging Compton Telescope COMPTEL is sensitive in the energy range 0.75 to 30 MeV. COMPTEL observed the Crab several times during the CGRO sky survey and CGRO Phase II. Both the Crab pulsar and nebula are detected over the entire COMPTEL energy range. The phase averaged energy spectra of the Crab Pulsar and Nebula are presented. The combined observations provide sufficient statistics for a phase resolved analysis of the Crab pulsar spectrum.

INTRODUCTION

COMPTEL, one of the four instruments aboard the Compton Gamma Ray observatory (CGRO), provided during its first 18 months of operation (Phase I of the CGRO-Mission) the first all sky survey in the low MeV range. In the subsequent 10 months selected objects of interest were observed (Phase II of the CGRO-Mission). COMPTEL has a field of view of 1 steradian and it has a positioning accuracy for strong sources better than 1°. A detailed instrumental description of COMPTEL is given by Schönfelder *et al.* /1/.

OBSERVATIONS AND ANALYSIS

During the Phase II of the CGRO-mission the Crab was twice within 25° of the instrument z-axis. The details of these two observations are summarized in Table 1. The listed exposure numbers are specified for the 1 to 3 MeV energy range.

Obs. #	T_{start} dd-mm-yy	T_{end} dd-mm-yy	Pointing l (°)	Pointing b (°)	Crab View Angle	Exposure (10^6 s·cm^2)
213.0	23-03-93	29-03-93	182.6	-8.2	3.1°	2.33
221.0	13-05-93	24-05-93	187.5	-5.9	3.0°	3.94

Table 1 COMPTEL observations of the Crab during Phase II of the CGRO-Mission

A detailed analysis of the Phase I data (validation period, observation 0, 1, 36.0, 36.5 and 39) is

already given elsewhere /2/. For these Phase I Crab observations the exposure was 27 10^7 cm^2 s in the 1 to 3 MeV interval. Here we add the Phase II data to these data sets.
Lightcurves are generated using contemporary Crab radio ephemerides /3/ by period folding of the photon arrival times after they were transformed to the solar system barycentre. The image reconstruction is performed in a three dimensional dataspace, defined by the photon scatter direction between the two detector layers and the Compton scatter angle using either a Maximum Entropy method or a Maximum Likelihood method (/1/ and references therein). The latter determines the source flux with the accociated statistical error.

RESULTS

The resulting lightcurve of the 0.75 to 10 MeV energy range for the combined data is shown in Fig. 1. Above 10 MeV no statistically significant pulsed emission was detected by COMPTEL.

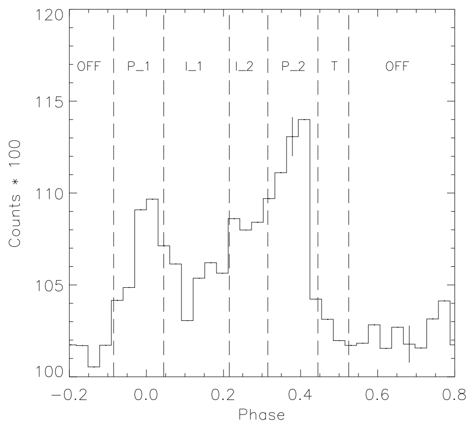

Fig. 1: The 33-bin Crab lightcurve for the energy interval 0.75-10 MeV. Only in this energy interval a statistically significant signal of the Crab pulsar is seen by COMPTEL. Indicated are the $\pm 1\sigma$ error bars.

Energy (MeV)	P_2/P_1 Ratio
0.75-1	2.83 ± 1.25
1-3	1.64 ± 0.24
3-10	1.76 ± 0.60
1-10	1.67 ± 0.22

Table 2 Ratio of second to first peak background subtracted counts in the Crab lightcurve for different energy intervals.

The COMPTEL lightcurve resembles much more that one seen at hard X-rays by OSSE /4/ than that seen above 50 MeV by EGRET /5/. It has a significant interpulse emission and a more intense second peak compared to the first peak. The latter is also seen from the ratio of excess counts above background in the lightcurve (Table 2). The COMPTEL ratios are within the statistical errors consistent with ratios in the 50-340 keV energy band (~ 1.4) measured by OSSE /4/. They are systematically greater than the EGRET ones (~ 0.4) above 50 MeV /5/.

As indicated in Fig. 1 the full period is divided into 6 phase intervals which are identical to the phase definitions used by Much *et al.* /2/. The total pulsed phase stretches from the begin of the first peak P_1 to the end of the trailer T. Although we determined the photon fluxes in smaller phase bins, we list in Table 3 and 4 the unpulsed flux and the pulsed flux, both averaged over the full period. For the combined data of Phase I and II we could split up the 1 to 10 MeV interval into smaller energy bins. Due to the low flux of the pulsed emission we could not split the 4-10 MeV range into smaller energy bands as done for the unpulsed emission.

We fitted the combined Phase I and II data with a single and a broken power law. The broken power law $I(E_\gamma) = 4.9 \cdot 10^{-5}(E_{MeV}/E_b)^{-\alpha}$ (α=1.83 if $E < E_b$ MeV, α=2.15 otherwise) describes the unpulsed COMPTEL data better than a single power law (Fig. 2). The break energy is $E_b = 5.5^{+15.2}_{-4.3}$ MeV. A fit of a single power law to the phase averaged pulsed COMPTEL data resulted in $I(E_\gamma) = 1.38 \cdot 10^{-4}(E_{MeV}/1.65)^{-2.35}$ (Fig. 1). A broken power law did not improve the fit result.

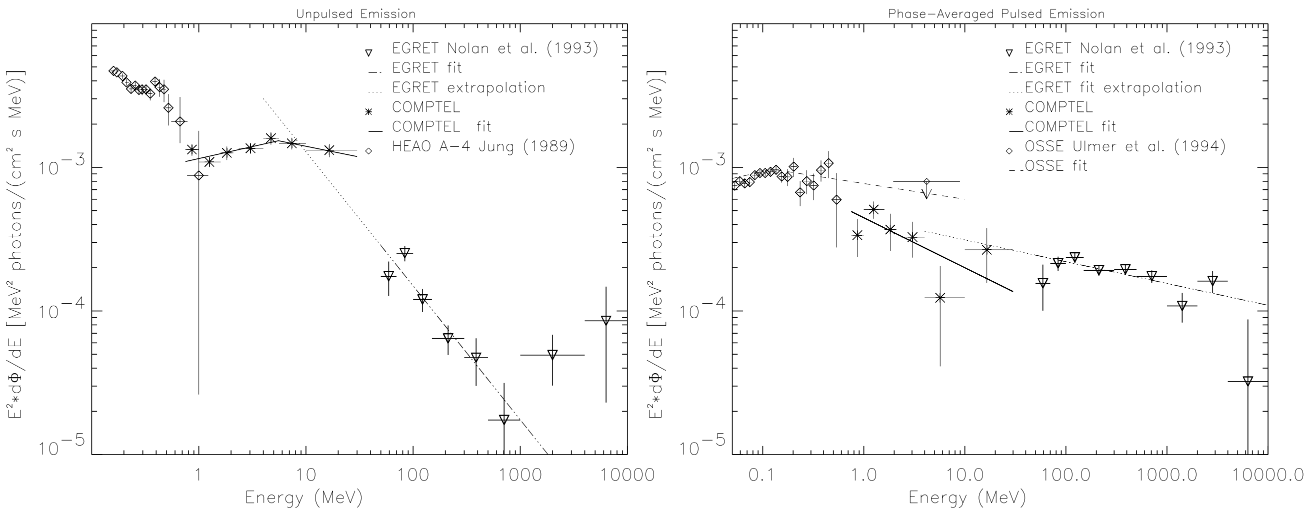

Fig. 2: The phase averaged pulsed and the unpulsed spectrum of the Crab emission. The COMPTEL data displayed are for the combined observations of Phase I and II.

Obs.	unpulsed photon fluxes (10^{-4} ph / (cm^2 s))			
#	0.75-1 MeV	1-3 MeV	3-10 MeV	10-30 MeV
213.0	4.26 ± 1.51	10.10 ± 1.60	4.22 ± 0.73	1.02 ± 0.35
221.0	4.05 ± 1.21	10.73 ± 1.29	3.59 ± 0.58	0.67 ± 0.22
Phase I+II	4.43 ± 0.42	8.11 ± 0.44	3.62 ± 0.21	0.88 ± 0.09
Obs.	phase averaged pulsed photon fluxes (10^{-4} ph / (cm^2 s))			
#	0.75-1 MeV	1-3 MeV	3-10 MeV	10-30 MeV
213.0	< 2.37	1.86 ± 1.26	< 1.12	< 0.82
221.0	1.11 ± 0.96	2.53 ± 1.02	0.91 ± 0.46	< 0.68
Phase I+II	1.12 ± 0.33	2.63 ± 0.35	0.36 ± 0.17	0.18 ± 0.07

Table 3 Crab pulsed and unpulsed fluxes in the COMPTEL standard energy intervals for observation 213, 221 and the combination of all Crab observations in Phase I and II. The quoted 1σ errors are statistical only. Upper limits are 2 σ.

Energy range (MeV)	unpulsed photon fluxes (ph / (cm^2 s))	phase averaged pulsed photon fluxes (ph / (cm^2 s))
1.0-1.6	$(4.08\pm0.32)\cdot10^{-4}$	$(1.92\pm0.26)\cdot10^{-4}$
1.6-2.1	$(1.88\pm0.20)\cdot10^{-4}$	$(0.55\pm0.16)\cdot10^{-4}$
2.36-4.0	$(2.36\pm0.21)\cdot10^{-4}$	$(0.57\pm0.16)\cdot10^{-4}$
4.0-10.0	-	$(0.18\pm0.12)\cdot10^{-4}$
4.0-5.6	$(1.14\pm0.11)\cdot10^{-4}$	-
5.6-10.0	$(1.15\pm0.11)\cdot10^{-4}$	-

Table 4 Crab pulsed and unpulsed photon fluxes for the finer binning of the 1 to 10 MeV range.

We generated phase resolved spectra for the combined Phase I and II data. Although in the majority of the cases COMPTEL data themselves cannot be used to determine the spectral slope of the phase-resolved spectra, they can be used thogether with the EGRET data /5/ to constrain the spectral behaviour. Alone, the spectrum of the second peak can be described with a simple power law. The spectrum of the first interpulse phase interval is consistent with a simple power law from 1 MeV to 1 GeV For the other three phase-resolved spectra, first peak, second interpulse and trailer phase interval, it can be concluded from the COMPTEL data that the EGRET power law does not continue into the COMPTEL energy range. These conclusions are in agreement with the results from the analysis of the Phase I data /2/.

SUMMARY

The spectrum of the unpulsed emission exhibit a bump in the low MeV range. As pointed out by Arons /6/, this can be explained within a relativistic magnetohydrodynamic model by a time variable shock structure causing higher γ-ray energy emitting particles to pile up at energies where they preferentially emit MeV photons. Except for the second peak, the combined phase resolved spectra of EGRET and COMPTEL are not consistent with single power laws. Therefore calculations of phase resolved spectra in the context of the standard pulsar models are encouraged.

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